A LABORATORY METHOD OF EVALUATING SLIPPERINESS

SEPT. 1958

NO. 21

Joint Highway Research Project

by

J.W. SHUPE

W.H. GOETZ

PURDUE UNIVERSITY
LAFAYETTE INDIANA

TECHNICAL PAPER

A LABORATORY METHOD OF EVALUATING SLIPPERINESS

TO: K. B. Woods, Director
Joint Highway Research Project

September 25, 1958

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

File: 9-6-4
Project: C-36-53D

Attached is a technical paper entitled, "A Laboratory Method of Evaluating Slipperiness" by J. W. Shupe and W. H. Goetz, Research Engineers on our staff. The paper was presented at the First International Skid Prevention Conference held September 8-12 in Charlottesville, Virginia.

Figures 2, 5a, 5b, 7a, 7b, 8a, and 8b are not included in the attached paper. Some of them are included in the report by Mr. Shupe entitled, "A Laboratory Investigation of Factors Affecting the Slipperiness of Bituminous Paving Mixtures" which was presented to the Advisory Board on May 21, 1958. Readers are referred to Figures 4, 6, 7, and 8a for Figures 2, 5a, 5b, and 7a respectively of this report. These figures were not included for economic reasons. They are photographs and will be supplied upon request.

The report is presented for the record.

Respectively submitted,

Harold L Michael

Harold L. Michael, Secretary

HLM:acc

Attachment

cc: A. K. Branham
J. R. Cooper
W. L. Dolch
W. H. Goetz
J. T. Hallett
F. F. Havey
G. A. Hawkins
G. A. Leonards
J. F. McLaughlin
R. D. Miles
R. E. Mills
B. H. Petty
M. B. Scott
C. E. Vogelgesang
J. L. Waling
J. E. Wilson
E. J. Yoder

Technical Paper

A Laboratory Method of Evaluating Slipperiness

by
J. W. Shupe, Research Engineer
and
W. H. Goetz, Research Engineer

Joint Highway Research Project
File No: 9-6-4
Project No: C-36-53D

Purdue University
Lafayette, Indiana
August 12, 1958

Prepared for Presentation at the
First International Skid Prevention Conference
Sept. 8-12, 1958, Charlottesville, Virginia

Not for Publication

(Subject to Change Before Publication)

A LABORATORY METHOD OF EVALUATING SLIPPERINESS

J. W. Shupe[1] and W. H. Goetz[2]

Currently there are sections of pavements in all classifications of our highway system which are potential skidding hazards. As the polishing effect of traffic continues to increase in intensity, the occurrence of these slippery pavements will also tend to increase, and the highway engineer is obligated to make a more positive contribution toward driving safety than to acknowledge and identify these sections of pavement as "Slippery When Wet."

The present accumulation of knowledge, available to assist the engineer in predicting the anti-skid characteristics of the many possible paving mixtures, is rather limited. In order to provide a better understanding of the slipperiness potential of various highway materials and to aid in the selection of pavement surfaces which exhibit satisfactory skid resistance, both initially and after an appreciable period of wear, a method of measuring pavement slipperiness in the laboratory was developed at Purdue University. It was felt that the control and consistency inherent in a laboratory study would permit a more accurate evaluation of the basic factors contributing to skid resistance than could be obtained in an investigation of the slipperiness of numerous existing highway surfaces. This report includes a description of the laboratory skid-test apparatus, the results of a field correlation study, and a discussion of the laboratory accelerated

1. Associate Professor, Applied Mechanics Department, Kansas State College, Manhattan, Kansas.
2. Professor, School of Civil Engineering, Purdue University, Lafayette, Indiana.

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

http://www.archive.org/details/laboratorymethod00shup

wear and polish procedure for simulating the polishing action of traffic.

LABORATORY SKID-TEST APPARATUS

The laboratory skid-test apparatus was designed to evaluate the relative skid resistance of both portland-cement and bituminous test specimens molded in the laboratory or cored from the pavement surface. A schematic diagram of the skid-test apparatus is shown in Figure 1. The circled numbers listed on this figure aid in identification of the essential features of the equipment. A more complete discussion of the skid-test apparatus is presented in reference (6).

The 6-in. diameter test specimen, 8, rests in a mold, 7, which is attached to the lower shaft, 4, and made to rotate at a constant angular speed of 2500 rpm, with the power supplied by a 40-hp electric motor, 1. During testing a rubber shoe, 9, which is illustrated in Figure 2, is forced against the rotating specimen with a unit pressure of 28 psi, and the torque developed in the top shaft is a measure of the skid resistance of the test specimen. This torque is reacted by a cantilever beam, 18, on which are mounted two Baldwin SR-4 strain gages. The torque developed in the top shaft results in a bending moment in the beam, causing a change in resistance in the strain gages, which is transmitted to the strain analyzer, 21, resulting in a pen deflection in the automatic recorder, 22.

Typical oscillograms of three test specimens are illustrated in Figure 3. The skid resistance of each of the surfaces is represented by a numerical value called the relative resistance value (RRV). This skid-test apparatus, like most of the methods for determining the anti-skid characteristics of test surfaces, evaluates the different surface types on a relative basis. No effort was made to convert this reading to a coefficient of friction.

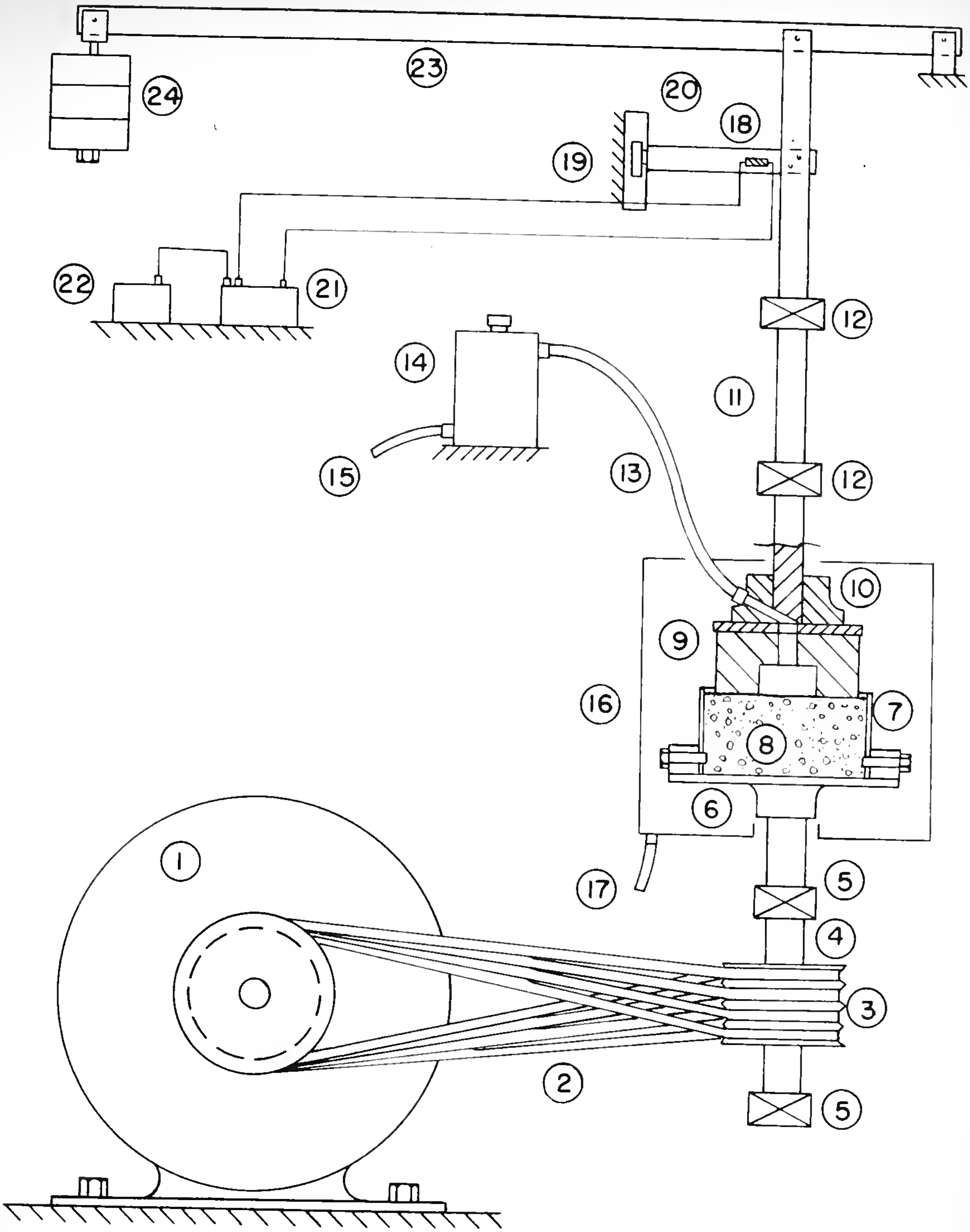

FIG. 1 SCHEMATIC DIAGRAM OF LABORATORY SKID-TEST APPARATUS

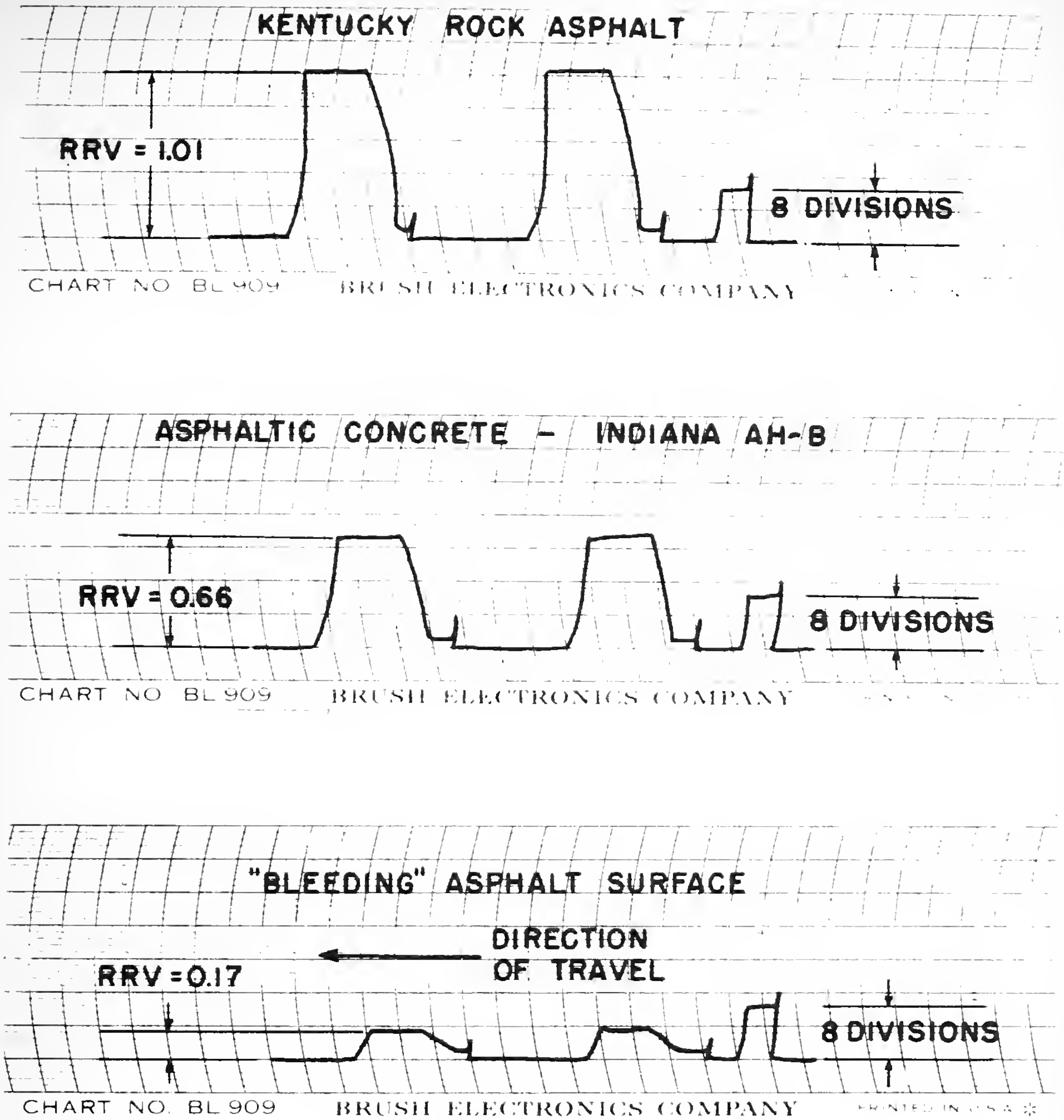

FIG. 3 OSCILLOGRAMS FROM THE LABORATORY SKID-TEST APPARATUS

Since previous research (3, 4) has indicated that Kentucky rock asphalt surfaces consistently exhibit excellent skid resistance when wet, test specimens composed of this material were used for the reference anti-skid surface. When the attenuation in the analyzer was adjusted to give a pen deflection of eight small divisions due to the calibration resistance, a pen deflection of approximately five of the major divisions resulted from the skid resistance generated by a Kentucky rock asphalt specimen. By arbitrarily assigning a value of unity (1.00) to the resistance developed by Kentucky rock asphalt, the relative resistance values of the other surface types could be determined to the nearest 0.01. The three surfaces represented in Figure 3 gave an RRV of 1.01, 0.66, and 0.17, respectively. As shown in Figure 3, each specimen was subjected to two 3-sec skids, and the second skid was used in evaluating the skid resistance. The trace for the second skid was usually sufficiently stable to accurately determine the RRV, whereas during the first skid the trace was frequently erratic.

All tests were performed with the surface in a wet condition. As illustrated in Figure 1, water was admitted to the specimen through a flexible line, 13, and after passing through the hole located in the center of the testing shoe, flowed over the surface of the specimen through the slots provided in the shoe. A shield of ⅛-inch steel plate, 16, was provided to catch the water and to prevent possible damage to equipment or personnel from flying particles.

Briefly summarizing the test procedure: 1. The motor is turned on, causing the specimen to rotate at 2500 rpm; 2. The water valve is opened and the recording equipment started to establish the zero reading on the oscillogram; 3. The weight, 24, is lowered manually to allow a 400-lb. force to bear on the test specimen for two 3-second periods, during which

the skid resistance is automatically recorded; and 4. The weight is secured and the water, recording equipment, and electric motor turned off. The total time required per test is approximately 15 seconds.

FIELD CORRELATION STUDY

A field correlation study was performed to compare the laboratory skid-test apparatus method of evaluating skid resistance with the results obtained by the passenger car stopping-distance test equipment developed by the Joint Highway Research Project of Purdue University (3). Seventeen bituminous and nine portland-cement concrete sections were tested in the wet condition by locking the brakes of a passenger car at an indicated speed of 30 mph and measuring the total distance required to skid to a stop on the wet pavement. Cores were then obtained from each test section and their relative resistance values were determined in the laboratory skid-test apparatus. No systematic sampling was made with regard to selecting sections having comparable traffic and age, so no conclusions should be drawn on the basis of these limited data as to the relative skid resistance of the various surface types.

The 26 different surfaces were grouped into six general classifications: 1. Kentucky rock asphalt; 2. Portland-cement concrete; 3. Gravel asphaltic concrete; 4. Gravel surface treatment; 5. Limestone asphaltic concrete; and 6. Limestone surface treatment. The results of the comparison of the field and laboratory methods of evaluating skid resistance are summarized in Figure 4. Relative resistance values are plotted along the ordinate with stopping distances indicated along the abscissa. Each plotted point represents the average stopping distance of three locked-wheel tests performed on the highway, and the average RRV for three cores obtained from each

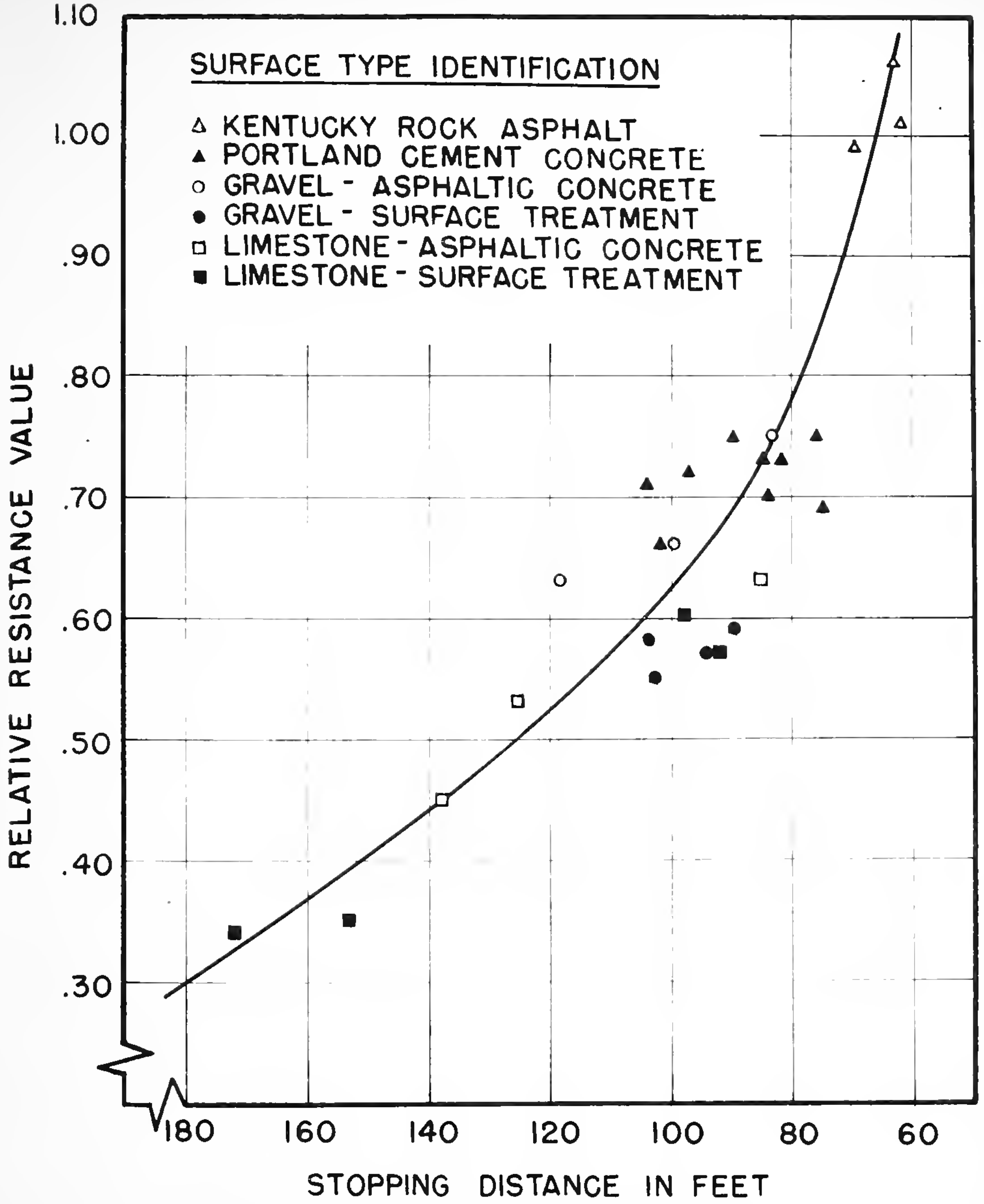

FIG. 4 COMPARISON BETWEEN FIELD AND LABORATORY SKID-TEST MEASUREMENTS

test section and evaluated in the laboratory skid-test apparatus.

There was fairly good agreement between the field and laboratory methods of evaluating skid resistance. In general, the fine-textured surfaces exhibited relatively higher skid-resistance values when measured by the laboratory procedure as compared to the field evaluation, while for the coarse-textured surfaces the reverse was true. The probable reasons for this apparent discrepancy, as well as for the lack of linearity between the field and laboratory methods of evaluation, pertain to the amount of water present on the surface and to the relative speeds between the surface and sliding rubber during testing. The laboratory equipment measures the degree of slipperiness at a constant relative speed of 30 mph between the shoe and surface at the mean radius of the area of contact, while the stopping-distance method determines an integrated average skid resistance over the entire speed range from the point at which the brakes are initially applied until the vehicle skids to a complete stop. It was felt that the laboratory apparatus would have shown somewhat better correlation with a towed-vehicle type of field test (5, 8) than with the stopping-distance method but, unfortunately, such a unit was not available for this study.

A detailed discussion of factors contributing to the variation between the results obtained with the field and laboratory methods of evaluating slipperiness is presented in reference (6). A consideration of these factors led to the conclusion that such discrepancies as exist tend to favor the laboratory method as giving a more realistic evaluation of the slipperiness of wet pavement surfaces than the stopping-distance method for speeds of 30 mph and upward, and that the laboratory skid-test apparatus is entirely satisfactory for a laboratory study of factors affecting the skid resistance of both portland-cement and bituminous paving mixtures.

THE STANDARD LABORATORY SPECIMEN

The primary consideration in forming a laboratory test specimen was to arrive at a surface condition which was representative of the texture that a similar mix would exhibit on a highway surface. Although for bituminous specimens the mixture had to possess sufficient surface durability to prevent disintegration under the severe action of the wearing procedure, which is discussed subsequently, stability and durability, as such, were not considered essential to a study of pavement slipperiness, and no measurements of these properties were made. For both portland-cement and bituminous specimens, the main criterion was the simulation of highway surface texture. To facilitate a comparison of the polishing characteristics of the various aggregates, each of the standard test specimens was composed entirely of one aggregate type.

Asphaltic Concrete

The standard laboratory asphaltic-concrete test specimen contained 4.5 percent of 85/100 penetration grade asphalt cement, based on the total weight of the mix. This asphalt content represented the best compromise between a leaner mix, in which the low asphalt content contributed to poor durability during the wearing procedure, and a richer mix, in which the excess of asphalt obscured the polishing characteristics of the aggregate. The aggregate gradation conformed to the specifications of the State Highway Department of Indiana for Asphaltic Concrete-Type B, and is listed in Table 1.

In preparing the laboratory specimens, the aggregate was separated into the various sieve-size fractions and recombined to the desired proportions. The asphalt and aggregate were heated separately to 300 ± 10 F, mixed for 2 minutes in a Hobart electric mixer, placed in a 6-in. diameter mold,

TABLE ..

Aggregate Gradation for Standard Laboratory Specimens

Passing Sieve	Retained on Sieve	Asphaltic Concrete	Portland Cement Concrete
1/2 in	3/8 in	12	25
3/8 in	No. 4	36	25
No. 4	No. 8	10	[illegible]
No. 8	No. 16	11	12
No. 16	No. 30	12	12
No. 30	No. 50	11	13
No. 50	No. 100	3	8
No. 100	No. 200	2	[illegible]
No. 200	Pan	3	[illegible]
		100	100

and vibrated for one minute with a Cleveland pneumatic vibrator. The resulting specimen, composed of a fairly open-graded asphaltic concrete with the asphalt content kept intentionally low to emphasize the aggregate contribution to the polishing characteristics of the mixture, was then ready for rolling as the initial step in the wear and polish procedure.

Portland Cement Concrete

The standard portland-cement concrete specimen was composed of a fairly well-graded aggregate with a high cement factor and sufficient water to result in a slump of approximately 1 to 2 inches. The aggregate gradation is listed in Table 1. Type I cement, without air entrainment, was used at the rate of 320 grams of cement for the 1660 grams of aggregate contained in each specimen.

The aggregate was mixed for 30 seconds in a Hobart electric mixer. The cement was added and the mixture was dry-mixed for another 30 seconds, with an additional 2 minutes of mixing after the water was combined with the dry ingredients. The batch was then placed in a removable mold, rodded 25 times, and allowed to set for 4 hours. It was then brushed lightly with a whisk broom to accomplish an initial "sandpaper" texture, moist-cured for 20 hours, removed from the mold, and placed in a 140 F water bath for 6 days.

After the specimen was removed from the bath it was mounted in a standard testing mold in the same manner in which samples cored from the pavement were prepared for testing. A paste consisting of three parts of type I portland cement to one part plaster of Paris, with sufficient water to provide adequate workability, was used in mounting the specimens. After the paste had set the specimen was ready for the initial skid test.

ACCELERATED WEAR AND POLISH PROCEDURE

In developing a laboratory accelerated wear and polish procedure, the primary criterion for each test specimen was to duplicate, as nearly as possible, the surface characteristics that a similar mix would exhibit after an appreciable amount of highway service under the action of heavy traffic. The procedure and associated instrumentation for simulating the polishing effect of traffic on both portland-cement and bituminous surfaces evolved after investigating different methods of polishing using over 130 test specimens. The procedure established for bituminous mixtures probably results in a closer simulation of surface texture between the field and laboratory specimens than is accomplished with the portland-cement specimens.

Asphaltic Concrete

It was originally intended to polish the bituminous specimens in the skid-test apparatus itself. Referring again to Figure 1, this was accomplished by putting a charge of abrasive material in the turbulence chamber, 14. The inlet pipe to the circular chamber was brazed on at an angle of 45 degrees to the tangent and, as the water swirled into the chamber, it agitated the abrasive into suspension and carried it down the outlet line directly onto the specimen. A rubber polishing shoe similar to, but of a harder compound than, the testing shoe was used in the wearing operation.

By adjusting the abrasive and the contact pressure to keep from overheating the polishing shoe, it was possible to grind the specimen down to essentially a level datum plane. However, there was little similarity between the surface texture of the resulting specimen and that of a similar mixture existing on the highway. In contrast to the laboratory specimens, well-worn sections of bituminous pavement exhibited a texture in which the

somewhat rounded and highly-polished coarse aggregate projected slightly above the surrounding matrix of asphalt and fine aggregate. This condition could not be simulated merely by grinding down the specimen.

In order to achieve the aggregate orientation that exists on a highway surface, the conical rollers, illustrated in Figure 5a, were developed to supply the rolling action that a surface receives from traffic. Figure 5b shows a specimen being rolled on [illegible] Minitrack apparatus. The Minitrack was built [illegible] for durability testing of bituminous specimens on a circular track [illegible], [illegible] only a slight modification was necessary to adapt the existing equipment to accommodate the [illegible]-in. diameter specimen. Rolling with this equipment resulted in a densification of the test specimen, with the coarse aggregate becoming somewhat more prominent at the surface than was noted at the completion of the molding procedure. As illustrated in Figure 5b, [illegible] post was located [illegible] above the crest of the rollers, and provided sufficient confinement to prevent excessive shoving of the mixture, without sacrificing an adequate amount of aggregate orientation.

Another operation which seemed to aid in developing a realistic test specimen was to polish the specimen after rolling in the Minitrack, using the conventional polishing shoe, previously described, with limestone filler suspended in water as an abrasive. This operation polished the coarse aggregate slightly and also appeared to erode away some of the surrounding matrix of fine aggregate and asphalt, so that the resulting surface closely approximated that of a specimen cored from the highway.

A final rolling of the specimen gave a very slight asphalt coating to the aggregate. Although this treatment did not exactly duplicate the oil drippings, worn rubber, and [illegible] that accumulates on some highways

during certain seasons of the year (1, 5), the skid resistance for this final condition was indicative of the susceptibility of different surfaces to this seasonal effect.

The rather complicated wear and polish procedure as finally evolved consists of the following steps:

1. The specimen is rolled for 2 min at 140 F in the Minitrack at 33 rpm with a total load on the two rollers of 100 lb.

2. The coarse-wear cycle occurs in the skid-test apparatus at 2500 rpm with a contact pressure of 5 psi. Each specimen is subjected to three wear series:

a). 300 g of #3/0 crushed quartz for 1 min.

b). 500 g of #5/0 crushed quartz for 1 min.

c). 400 g of limestone filler for 1 min.

3. Aggregate orientation and surface texture are developed in the Minitrack at 33 rpm as follows:

a). 2 min rolling at 140 F.

b). 10 min wear with limestone filler.

4. A fine-polish cycle is given the specimen in the skid-test apparatus at 2500 rpm in three additional series:

a). 250 g limestone filler, 30 sec, 15 psi contact pressure.

b). 250 g limestone filler, 30 sec, 28 psi contact pressure.

c). No abrasive, 30 sec, 28 psi contact pressure.

5. The final operation is to coat the surface aggregate with a light asphalt film by rolling at 140 F for 1 min.

Figure 6 illustrates the variation in skid resistance that a bituminous test specimen experiences during the entire wear and polish procedure. The top curve is for a specimen made with sandstone, and illustrates

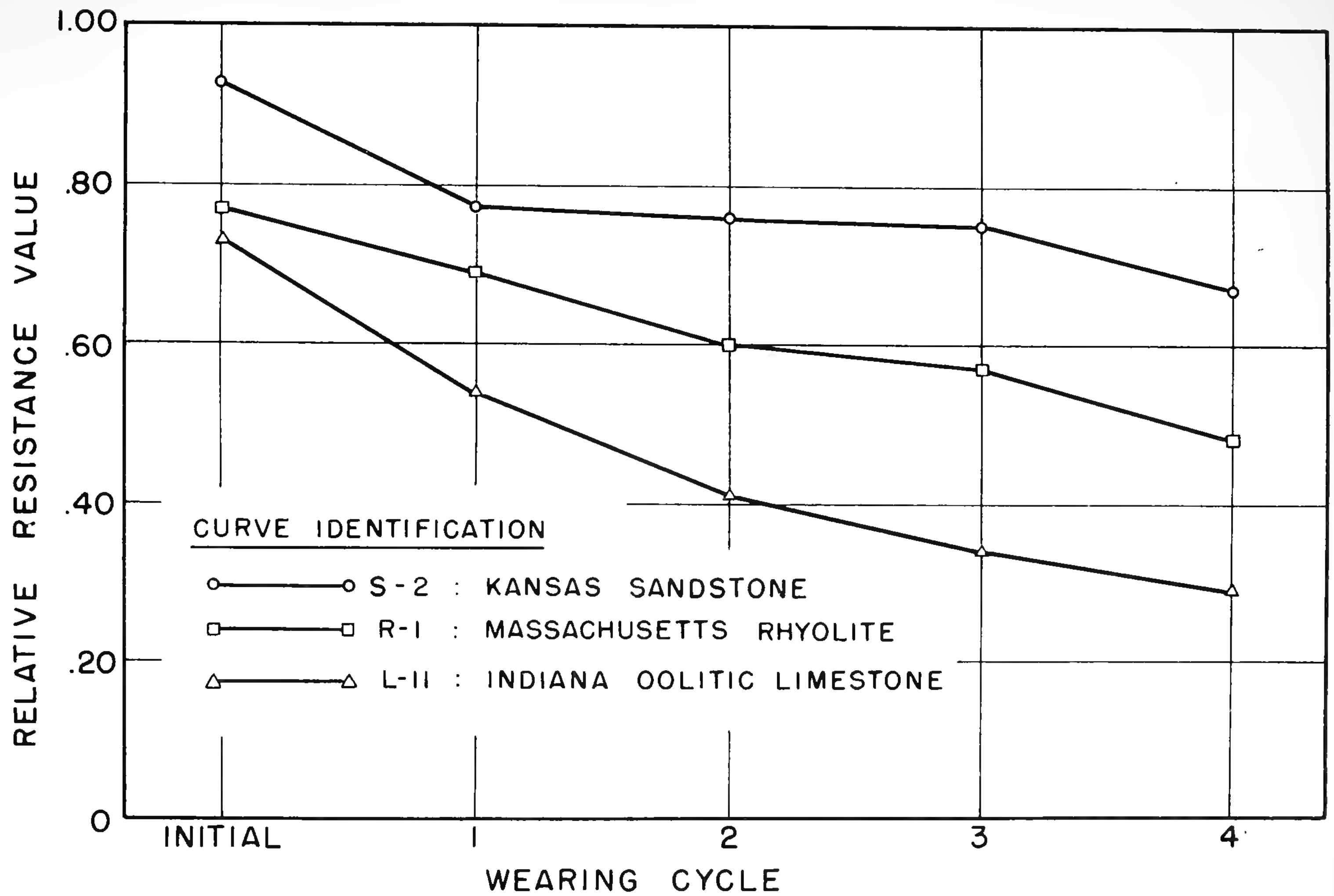

FIG. 6 VARIATION IN SKID RESISTANCE OF BITUMINOUS MIXTURES WITH WEAR

the relatively high resistance to polishing of bituminous mixtures composed of this aggregate. The middle curve is for a specimen containing rhyolite which exhibits appreciable less resistance to polishing than the specimen composed of sandstone. The bottom curve represents the results for a specimen made from oolitic limestone, which possessed very little resistance to polishing.

The five points plotted for each of the aggregates in Figure 6 correspond to a specific position in the wear and polish procedure. The initial relative resistance values were obtained after the specimen had been vibrated for a minute and allowed to cool. The other four points correspond, respectively, to values determined immediately following initial rolling, coarse polish, fine polish, and final rolling. In comparing the polishing characteristics of the different specimens, the results obtained at the completion of fine polishing (Wear cycle No. 3 of Fig. 6) are probably the most significant. At this point in the wearing procedure the test specimen exhibits a clean, smooth surface with a texture similar to that of a well-worn bituminous pavement. Figure 7a indicates the appearance of a typical limestone specimen after the fine-polish cycle.

Portland-Cement Concrete

Subjecting a portland-cement concrete specimen to the entire wear and polish procedure used for bituminous specimens, only resulted in a slight amount of wear of the fine-aggregate mortar and failed to expose an appreciable quantity of coarse aggregate. To obtain a comparison of the anti-skid characteristics of different portland-cement mixes it was necessary to subject the specimens to a more severe wearing procedure than had been used for asphaltic concrete.

The modified wear and polish procedure for portland-cement concrete is as follows:

1. The mortar is exposed to polishing by subjecting the concrete specimen, with a lightly-brushed "sandpaper" surface, to the entire wear and polish procedure used for bituminous mixtures, with the following exceptions:

a). Both rolling operations are omitted.

b). For the coarse-wear cycle, contact pressure is 15 psi.

c). For the fine-polish cycle, contact pressure is 28 psi.

2. To accomplish aggregate exposure, the top 1/4 inch of the specimen is sawed off with a masonry saw equipped with a diamond blade.

3. The total wearing procedure, to which the specimen was subjected prior to sawing, is again given the sawed face to subject the exposed mortar and aggregate to a polishing action.

Figure 7b illustrates the appearance of a portland-cement concrete specimen containing traprock at the completion of the total wearing procedure on the sawed specimen. Figures 8a and 8b are of two concrete specimens containing oolitic limestone in the "prior to polishing" and the "mortar polished" condition. The variation in skid resistance corresponding to these three conditions, i.e. prior to polishing, mortar polished, and aggregate polished, are shown in Figure 9 for the same three aggregates contained in the bituminous specimens of Figure 6. Except for the initial condition, the relative resistance to polishing of the three aggregates is the same for both portland-cement and bituminous mixtures.

It is doubtful if the texture of a portland-cement concrete specimen, which is sawed and worn to the "aggregate-polished" condition, simulates the texture of a highway section as closely as either the bituminous specimens

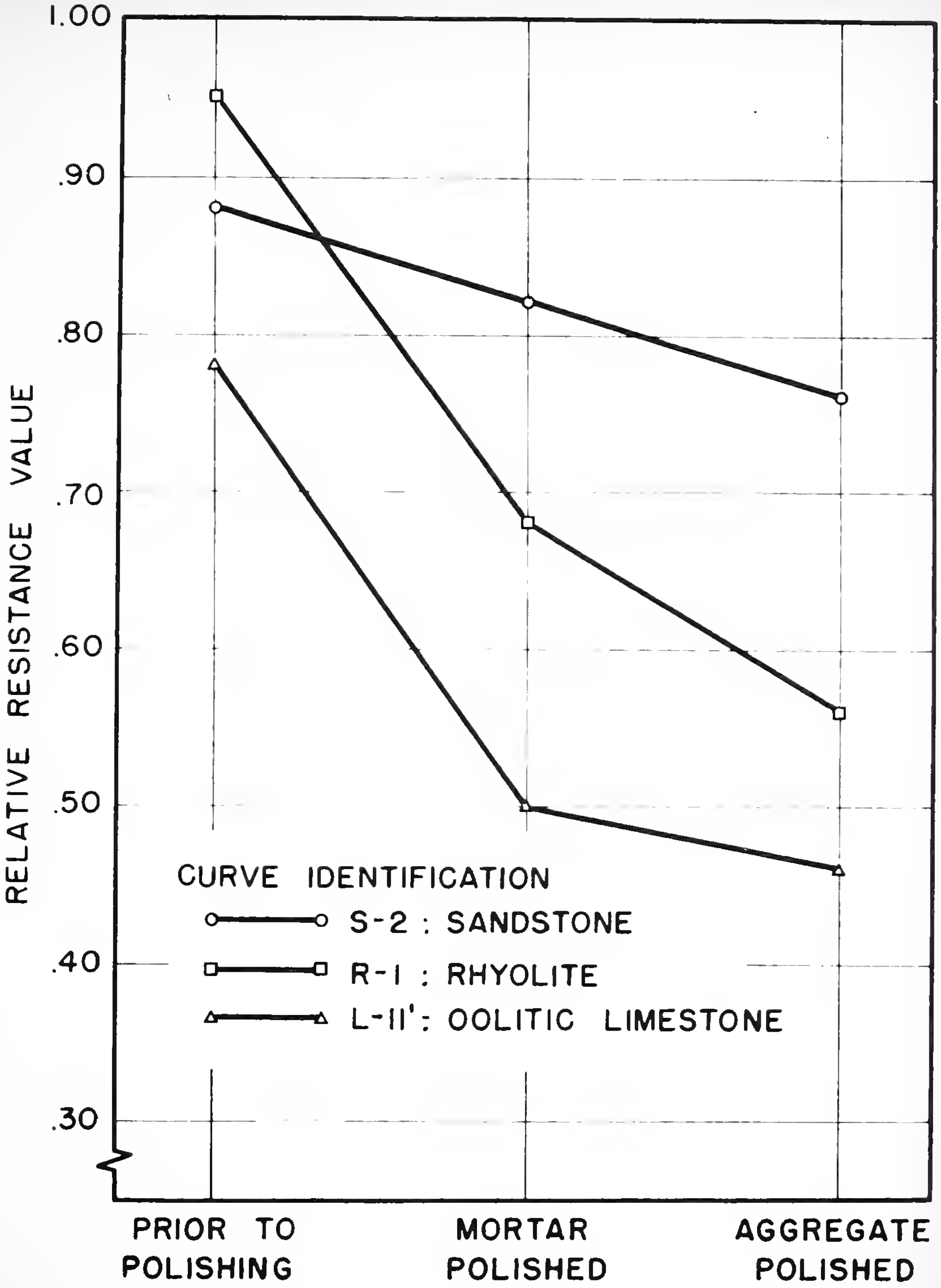

FIG. 9 POLISHING CHARACTERISTICS OF PORTLAND CEMENT CONCRETE

or the portland-cement specimens for the initial and "mortar-polished" conditions. In a fairly extensive examination of portland-cement concrete highways in Indiana, some of which were over 30 years old, not a single section of pavement was observed that exhibited as much coarse aggregate exposure as is shown in Figure 7b, except where scaling or spalling occurred. Most of the highways had a texture similar to the mortar-polished condition of Figure 8b, and on a few of the oldest sections the original finishing marks were even discernible. However, if extremely high traffic is anticipated, this final condition, which is representative of the pavement after an appreciable area of the coarse aggregate is exposed to traffic, may be somewhat more realistic.

CONCLUSION

The laboratory skid-test apparatus has operated satisfactorily for 15 months, while the wear and polish procedure has been in use for about 9 months. Current or completed research with this equipment, some of which is reported elsewhere in the Proceedings (7), includes a study of the polishing characteristics of mineral aggregates in both portland-cement and bituminous mixtures; the effect of surface texture and initial aggregate shape on the skid resistance of bituminous mixtures; the anti-skid properties of various fine-grained non-skid surface treatments; and the effect of blending a polish-resistant material with a polish-susceptible aggregate in improving the skid resistance for both portland-cement and bituminous paving mixtures.

The equipment has exhibited excellent reproducibility in obtaining test results. Initially three replicate specimens were molded for each test series, but due to the small variation in test values of the three specimens, the number per series has been decreased to one for the recent studies.

In developing this equipment every effort was made to simulate the envelopment of the components of a highway surface by the sliding rubber tire which occurs when a driver attempts an emergency stop on a wet pavement at normal driving speed. The high relative speed between the testing shoe and the test specimen, the rubber compound, the 28 psi unit pressure, and the simulated tread pattern of the testing shoe were all selected to encourage the type of contact which occurs between a wet pavement surface and a sliding passenger-car tire with a normal tread pattern.

It was not the intention to have the standard wear and polish procedure, for either the portland-cement or the bituminous specimens, result in the ultimate slippery condition for all surface types. It was felt that holding the wearing effort constant would result in a relative measure of the resistance to polishing of the different paving mixtures that would be more realistic than subjecting each of the specimens to sufficient polishing to cause it to arrive at its most slippery condition.

The laboratory testing equipment and procedure may be used in either of two ways in predicting the anti-skid characteristics of paving mixtures. The most direct approach is to duplicate the proposed mixture in the laboratory, subject it to the accelerated wear and polish procedure, and observe the resistance of the mixture to polishing.

The second approach, which is somewhat more basic, is to use the equipment to evaluate the skid-resistant contribution of each of the many variables on which pavement slipperiness is dependent. If a weighted factor can be assigned to such variables as aggregate texture or particle shape, an estimate of the skid resistance of the mixture may be possible by summing the effect of the component parts. Petrographic and chemical analyses may help in establishing the effect of the basic aggregate propertise on the

polishing characteristics of paving mixtures. Other measuring tools and additional research are required along this line, but the basic approach appears to hold much promise in explaining variations in resistance to skidding.

In either case, however, a laboratory procedure for pretesting the skidding potential of highway materials will aid the engineer in predicting the anti-skid characteristics of a proposed pavement, and will permit the inclusion of skid resistance as an additional design parameter in selecting a suitable paving mixture.

ACKNOWLEDGMENTS

The authors acknowledge the complete cooperation of the State Highway Department of Indiana in planning and performing the field testing program. The rubber testing and polishing shoes were furnished by the Firestone Tire and Rubber Company. Mr. Morris Stewart was in charge of the laboratory testing program.

BIBLIOGRAPHY

1. Giles, C. G., "The Skidding Resistance of Roads and the Requirements of Modern Traffic," Proceedings, Institute of Civil Engineers, London, England, Vol. 6, pp. 216-249, 1957.

2. Goodwin, W. A. and Whitehurst, E. A., "A Device for the Determination of Relative Potential Slipperiness of Pavement Mixtures," Paper presented at the 37th Annual Meeting of the Highway Research Board, 1958.

3. Grunau, D. L., and Michael, H. L., "Skid Characteristics of Pavement Surfaces in Indiana," Bulletin No. 139, Highway Research Board, 1956.

4. Moyer, R. A., "Skidding Characteristics of Automobile Tires on Roadway Surfaces and Their Relation to Highway Safety," Bulletin No. 120, Iowa Engineering Experiment Station, Ames, Iowa, 1934.

BIBLIOGRAPHY

5. Moyer, R. A. and Shupe, J. W., "Roughness and Skid Resistance Measurements of Pavements in California," Bulletin No. 37, Highway Research Board, 1951.

6. Shupe, J. W. and Goetz, W. H., "A Laboratory Method for Determining the Skidding Resistance of Bituminous Paving Mixtures," Paper presented at the 61st Annual Meeting of the American Society for Testing Materials, Boston, Mass., 1958.

7. Shupe, J. W. and Lounsbury, R. W., "Polishing Characteristics of Mineral Aggregates," Proceedings, First International Skid Prevention Conference, University of Virginia, Charlottesville, 1958.

8. Skeels, P. C., "Measurement of Pavement Skidding Resistance by Means of a Simple 2-Wheel Trailer," Paper presented at the 37th Annual Meeting of the Highway Research Board, 1958.